4 Field Data Collection and Analysis[1]

The Willapa Bay field data collection program was executed by Evans-Hamilton, Inc. (EHI) under task-order contract with the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. The program incorporated measurements of waves, currents (point measurements and profiles through the water column), water level, salinity (conductivity and temperature), wind velocity, air temperature, and air pressure. Each of three field deployments included five wave and current stations, four combined water-level and salinity recording stations, and one weather station. Wave and current instruments were arranged on the same bottom mounts, and stations were divided geographically into two groups as the entrance gauges and as the inner, or back-bay, gauges. Water-level recording stations were distributed around the periphery of the bay and in the river channels. The weather (meteorological) station was deployed near the center of Willapa Bay, approximately 10 m above the water surface. The instruments stored data internally, with measurement times referenced to Greenwich Mean Time (GMT). Two cruises were conducted to measure baywide variations in the current structure and to define the vertical density (salinity) structure of the water column.

Data collection was conducted both for project-specific objectives and for documenting the existing physical processes as a baseline for monitoring changes, should channel dredging take place. Project-specific objectives concerned primarily acquisition of data to verify numerical simulation models of the bay hydrodynamics (Chapter 6) and the waves at the entrance to Willapa Bay (Chapter 5). The data also served to characterize the hydrodynamic environment at the Willapa Bay entrance for assessing navigation reliability of the various project design alternatives discussed in Chapter 2.

The data collection program was initially developed at the ERDC Coastal and Hydraulics Laboratory (CHL), to meet the project objectives, including selection of instruments, rates and duration of sampling, and length of deployments. EHI subsequently reviewed and offered recommendations for the program. The instrument types and suites were based on experience of CHL in data collection at the mouth of the Columbia River and in other projects. EHI constructed mounts

[1] Written by Mr. Keith Kurrus, Ms. Carol Titus, Mr. Ken FitzGerald, and Ms. Suzanne Giles of Evans-Hamilton, Inc., and Dr. Vladimir Shepsis and Mr. Hugo Bermudez of Pacific International Engineering[PLLC].

to house the instruments based upon cumulative experience in data collection at Willapa Bay and similar ocean-estuary environments.

Wave Measurements

A combination of directional and standard wave measurements (wave height and period) was made during the Willapa Bay field effort. Two types of systems were deployed, and station locations are shown in Figure 4-1. For the entrance gauges (Stations 1, 2, 3 and 10, 11, 12), directional wave measurements were made with SonTek, Inc., Hydra instruments incorporating a SonTek Acoustic-Doppler Velocimeter (ADVOcean) probe coupled with a Paroscientific, Inc., digi-quartz pressure sensor. Current and pressure readings were collected once an hour, starting at the top of the hour, and instruments were set to collect 4,096 data points at 2 Hz. For the back-bay gauges (Stations 4, 5, and 13), pressure readings were collected with a digi-quartz pressure sensor connected externally to a SonTek Acoustic Doppler Profiler (ADP). Pressure readings were collected once an hour, starting 1.5 min before the hour, recording 1,024 data points at 1 Hz.

The ADPs coupled with a Paroscientific pressure sensor operated with two sampling schemes, one for measuring currents and one for measuring waves. Because the current data were averaged over 3-min intervals and centered at the top of the hour, the pressure data had to be synchronized with the current readings, causing the awkward start time. All pressure sensors had a measuring range of 0-45 psia. Field service dates and the parameters measured at each station are summarized in Table 4-1.

Instruments were deployed on the seabed on two types of mounts, either on a tripod or on a trawl-resistant frame. Mounts were selected based on the anticipated sediment type, predicted waves and currents, and site-specific characteristics that would have bearing upon the success of the data collection effort. Tripods provide the flexibility of mounting multiple instruments on one deployment package while maintaining a stable platform. They also provide some protection from instrument burial by shifting sand. Figure 4-2 shows a tripod with an ADP current meter and a Hydra system mounted on the tripod.

The trawl-resistant frames were originally designed to provide protection for the instruments mounted in the frame and to incorporate a low profile to avoid damage by local vessel activity. Trawl-resistant frames also possess a wider footprint to hinder settling in softer sediments.

Before deployment, one or two cross-channel bathymetry transects were obtained to aid the placement of each instrument package. Deployment and recovery positions were recorded during both deployment and retrieval cruises. The survey vessel was equipped with differential Global Positioning System (GPS) (Trimble DSM-Pro), which provides ±1-m accuracy. Water depths were measured with an echosounder on the survey vessel. Bar checks were conducted to calibrate the echosounder. Deployment and recovery information is summarized in Tables 4-2 and 4-3.

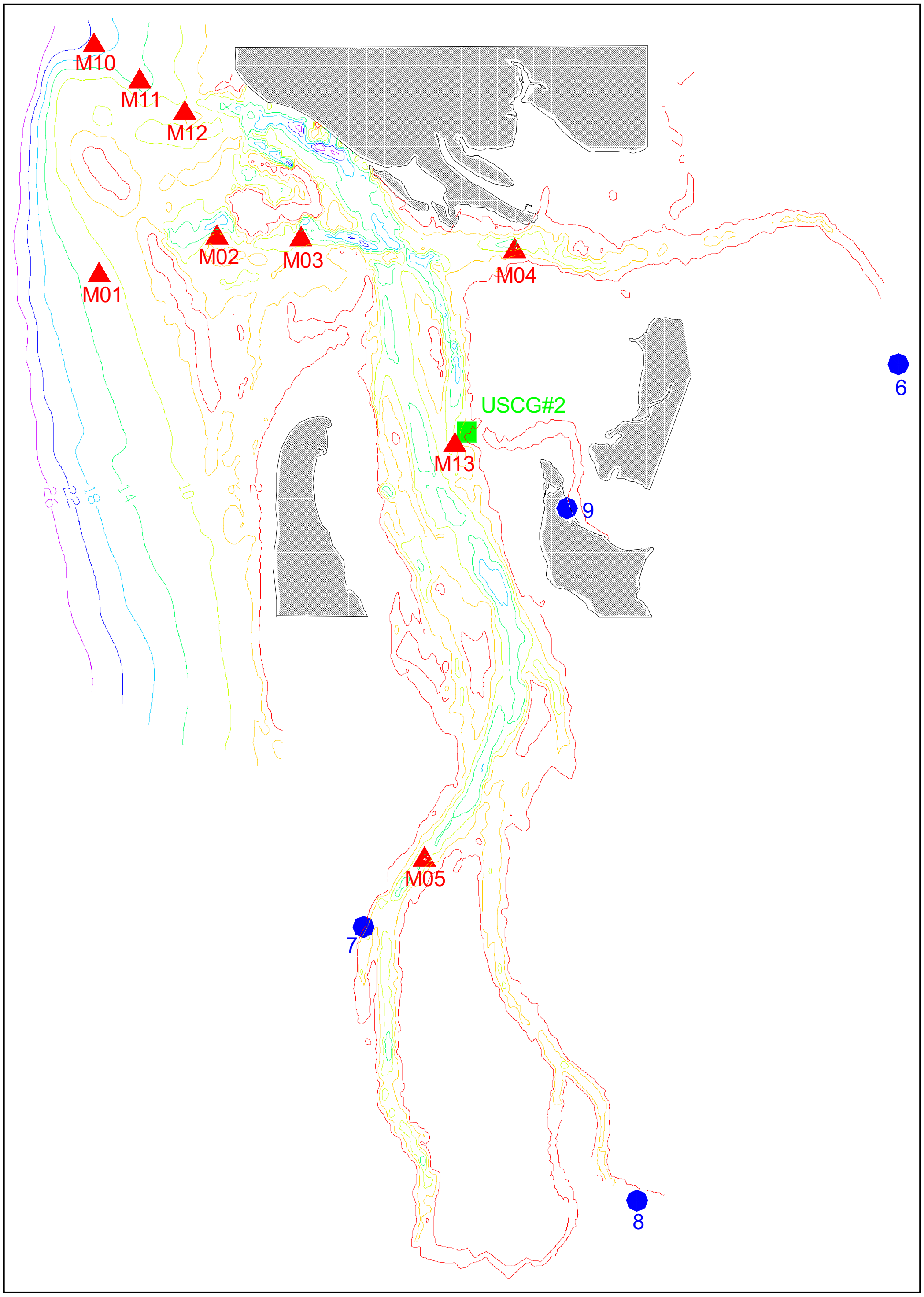

Figure 4-1. Location of current meters and wave gauges (triangles), water-level gauges (circles), and meteorological station (squares) in Willapa Bay

Table 4-1
Willapa Bay Data-Collection Schedule

		1998				
		Deployment 1	Deployment 2	Deployment 3	Deployment 4	
Station No.	**Parameters Measured**	**August**	**September**	**October**	**November**	**December**
Waves						
1[1]	Current speed, current direction, temperature, pressure, pitch, roll, and heading	26th	-10th 10th	-9th 9th	-18th	
2[1]		25th	-9th 11th	-7th 14th	-17th	
3[1]		25th	-9th 11th	-7th 14th	-11th	
10[1]						
11[1]						
12[1]						
Wave Height & Period						
3	Pressure				17th-	16th
4		26th	-9th 10th	-13th 14th	-11th	
5		25th	-10th 10th	-12th 14th	-12th	
13					17th-	17th
Currents						
1	Current speed, current direction, temperature, pitch, roll, and heading	26th	-10th 10th	-9th 9th	-18th	
2		25th	-9th 11th	-7th 14th	-17th	
3		25th	-9th 11th	-7th 14th	-11th 17th-	16th
4		26th	-9th 10th	-13th 14th	-11th	
5		25th	-10th 10th	-12th 14th	-12th	
13					17th-	17th
MicroCAT						
1	Conductivity and temperature	26th	-10th 10th	-9th 9th	-18th	
Water- Level Gauges						
4	Conductivity, temperature, and pressure	26th	-9th 10th	-13th 14th	-11th	
6 (South Bend)		13th	-16th 16th	-21st 21st	-17th 17th-	17th
7 (Nahcotta)		12th	-15th 15th	-22nd 22nd	-17th 17th-	18th
8 (Naselle River)		12th	-15th 15th	-22nd 22nd	-18th 18th-	18th
9 (Bay Center)		11th	-16th 16th	-21st 21st	-17th 17th-	17th
13					17th-	17th
Meteorological Station						
Bay Center Channel Light, Number 2	Wind speed, wind direction, air temperature, and barometric pressure	12th	-11th 11th	-7th 7th	-17th 17th-	17th
Field Service Dates						
Waves/Currents		24th - 26th	9th-11th	7th-9th & 11th-14th	11th-13th & 16th-18th	16th - 17th
Water-Level Gauges (Stations 6-9)		11th - 13th	15th - 16th	21st - 22nd	17th - 18th	17th - 18th
Meteorological Station		12th	4th & 11th	7th	17th	17th
ADCP Transects[2]					17th - 18th	
Profiling CTD Survey[3]					16th – 18th	

[1]Directional.
[2]ADCP = Accoustic Doppler Current Profiler.
[3]CTD = Conductivity, temperature, and depth (pressure) sensor – primarily deployed to measure water salinity as a function of depth.

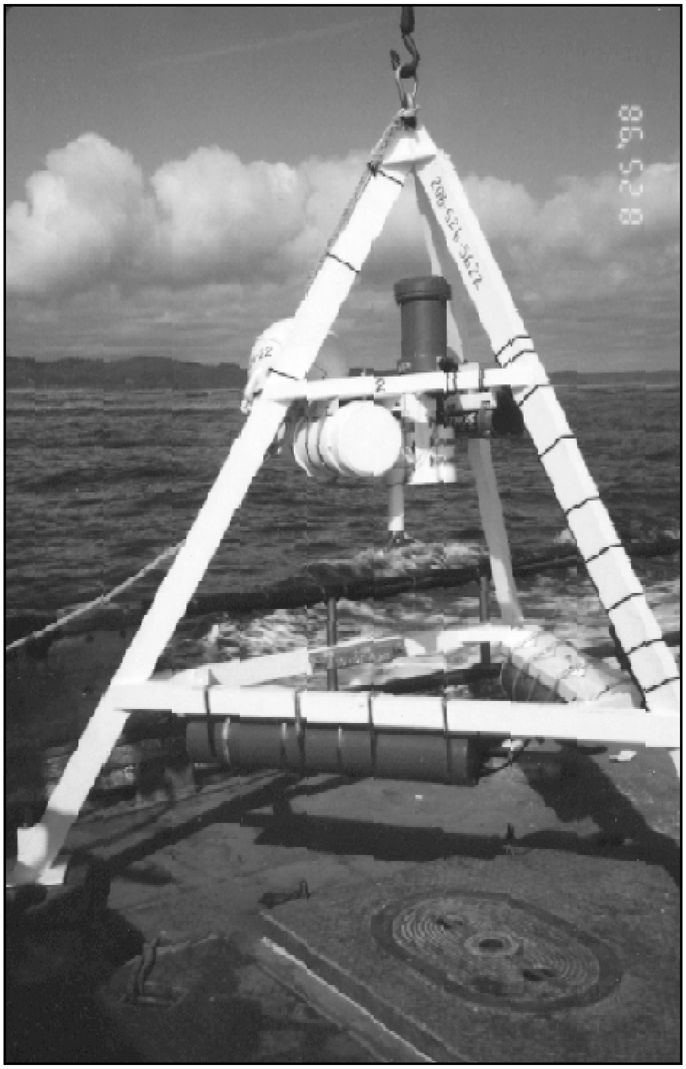

Figure 4-2. Tripod mount as deployed in Willapa Bay

Data reduction and quality control procedures for wave measurements

Processing and analysis of the Willapa Bay wave data were performed by Pacific International Engineering (PIE) under the direction of ERDC. The work included quality assurance checks of the recorded data and spectral analysis. Five stations were occupied; the three located at the entrance measured directional waves, and the two in the bay measured non-directional waves.

Wave data from each deployment were first checked for inconsistencies by developing time-series plots of heading, pitch, and roll recorded by each ADVOcean or ADP instrument. Pressure time-series were generated and analyzed to identify discrepancies in the record. Deployment and recovery information is summarized in Table 4-2.

Table 4-2
Tripod Deployment and Retrieval Locations

Station No.	Date GMT	Position Latitude (N) Longitude (W)	Position[1]	Time GMT	Water Depth[2]	Date GMT	Position Latitude (N) Longitude (W)	Position[1]	Time GMT	Water Depth[2]	Comments
Deployment No. 1						**Retrieval No. 1**					
1	08/26/98	46 41.002' N 124 08.751' W	X 725,726 Y 513,536	18:00	38 (11.6 m)	09/10/98	46 41.001' N 124 08.745' W	X 725,750 Y 513,492	17:59		
2	08/25/98	46 41.663' N 124 05.843' W	X 738,057 Y 516,908	23:21	33 (10.1 m)	09/09/98	46 41.664' N 124 05.848' W	X 738,037 Y 516,917	18:14		ADP missing profiles because of hardware problems.
3	08/25/98	46 41.818' N 124 03.817' W	X 746,563 Y 517,464	23:02	33 (10.1 m)	09/09/98	46 41.818' N 124 03.817' W	X 746,563 Y 517,464	18:30		ADVOcean flooded, disabling compass, tripod hard to pull up.
4	08/26/98	46 41.756' N 123 58.371' W	X 769,299 Y 516,072	16:38	32 (9.8 m)	09/09/98	46 41.755' N 123 58.387' W	X 769,230 Y 516,073	18:58		Tripod spun ~125 deg after ~4 days, depth & position the same.
5	08/25/98	46 31.286' N 123 59.956' W	X 759,855 Y 452,796	18:07	40 (12.2 m)	09/10/98	46 31.268' N 123 59.830' W	X 760,379 Y 452,661	21:34	18 (5.5 m)	Mount flipped after ~2 days and moved ~500 ft east.
Deployment No. 2						**Retrieval No. 2**					
1	09/10/98	46 41.023' N 124 08.717' W	X 725,871 Y 513,576	18:30	37 (11.3 m)	10/09/98	46 41.002' N 124 08.710' W	X 725,896 Y 513,533	18:59		ADVOcean leaked, disabling compass, ADP missing profiles.
2	09/11/98	46 41.765' N 124 05.834' W	X 738,122 Y 517,524	18:22	40 (12.2 m)	10/07/98	46 41.763' N 124 05.834' W	X 738,120 Y 517,516	15:22		
3	09/11/98	46 41.800' N 124 03.747' W	X 746,849 Y 517,343	18:49	33 (10.1 m)	10/07/98	46 41.801' N 124 03.754' W	X 746,820 Y 517,352	15:49		Large green seaweed caught on tripod, hard to pull up.
4	09/10/98	46 41.757' N 123 58.423' W	X 769,081 Y 516,091	16:35	33 (10.1 m)	10/13/98	46 41.757' N 123 58.423' W	X 769,081 Y 516,091	00:25		Tripod sunk ~4 ft, large green seaweed caught on tripod.
5	09/10/98	46 31.296' N 123 59.995' W	X 759,692 Y 452,859	23:29	46 (14.0 m)	10/12/98	46 31.300' N 123 59.990' W	X 759,715 Y 452,881	22:35		Mount appears to be acting like a sediment trap.
Deployment No. 3						**Retrieval No. 3**					
1	10/09/98	46 41.005' N 124 08.721' W	X 725,859 Y 513,732	19:29	39 (11.9 m)	11/18/98	46 41.043' N 124 08.720' W	X 725,865 Y 513,698	18:00	40 (12.2 m)	
2	10/14/98	46 41.850' N 124 05.841' W	X 738,110 Y 517,919	21:54	30 (9.1 m)	11/17/98	46 41.849' N 124 05.897' W	X 737,883 Y 518,047	00:04	21 (6.4 m)	Leg broke off tripod during retrieval.
3	10/14/98	46 41.851' N 124 03.848' W	X 746,444 Y 517,675	22:11	33 (10.1 m)	11/11/98	46 41.853' N 123 03.842' W	X 746,467 Y 517,681	20:28	27 (8.2 m)	
4	10/14/98	46 41.749' N 123 58.487' W	X 768,814 Y 516,054	18:42	31 (9.4 m)	11/11/98	46 41.759' N 123 58.479' W	X 768,849 Y 516,113	21:09	22 (6.7 m)	
5	10/14/98	46 31.319' N 123 59.920' W	X 760,017 Y 452,987	20:17	39 (11.9 m)	11/12/98	46 31.338' N 123 59.938' W	X 759,943 Y 453,105	23:20	40 (12.2 m)	
Deployment No. 4						**Retrieval No. 4**					
3	11/17/98	46 41.812' N 124 03.824' W	X 746,534 Y 517,432	00:26	22 (6.7 m)	12/16/98	46 41.812' N 124 03.827' W	X 746,516 Y 517,428	18:46	32 (9.8 m)	
13	11/17/98	46 38.532' N 123 59.710' W	X 762,838 Y 496,743	22:46	24 (7.3 m)	12/17/98	46 38.556' N 123 59.709' W	X 762,844 Y 496,891	13:00	30 (9.1m)	

[1]In feet referred to the North American Datum of 1983.
[2]In feet referred to mean lower low water (mllw).

Table 4-3
Willapa Bay Equipment Log

Deployment					Acoustic Doppler Profiler (ADP)					ADVOcean			PAROS		MicroCAT	
Deployment Number	Station Number	Water Depth[1]	Deployment Date	Retrieval Date	Serial Number	Frequency kHz	Distance of Transducer off Bottom m	Cell Size m	Blank Dis. M	Serial No.	Frequency MHz	Distance of Transducer off Bottom m	Serial No.	Distance to Pressure Port off Bottom m	Serial No.	Distance off Bottom m
1	1	11.6	08/26/98	09/10/98	C50	1,500	1.93	0.5	0.4	B62	5.0	1.09	70621	1.28	37SI19004-0687	1.86
	2	10.1	08/25/98	09/09/98	C35	1,500	1.93	0.5	0.4	B94	5.0	1.09	72688	1.28		
	3	10.1	08/25/98	09/09/98	C36	1,500	1.93	0.5	0.4	B107	5.0	1.09	72690	1.28		
	4	9.8	08/26/98	09/09/98	C30	1,500	1.93	0.5	0.4				72689	1.28		
	5	12.2	08/25/98	09/10/98	C32	1,500	0.47						70361	0.51		
2	1	11.3	09/10/98	10/09/98	C35	1,500	1.93	0.5	0.4	B94	5.0	1.09	72688	1.28	37SI19004-0687	1.86
	2	12.2	09/11/98	10/07/98	C50	1,500	1.93	0.5	0.4	B62	5.0	1.09	70621	1.28		
	3	10.1	09/11/98	10/07/98	C36	1,500	1.93	0.5	0.4	B73	5.0	1.09	72690	1.28		
	4	10.1	09/10/98	10/13/98	C30	1,500	1.93	0.5	0.4				72689	1.28		
	5	14.0	09/10/98	10/12/98	C32	1,500	0.47	0.5	0.4				70361	0.51		
3	1	11.9	10/09/98	11/18/98	C50	1,500	1.93	0.5	0.4	B62	5.0	1.09	70621	1.28	37SI19004-0687	1.86
	2	9.1	10/14/98	11/17/98	C35	1,500	1.93	0.5	0.4	B118	5.0	1.09	72688	1.28		
	3	10.1	10/14/98	11/11/98	C36	1,500	1.93	0.5	0.4	B73	5.0	1.09	72690	1.28		
	4	9.4	10/14/98	11/11/98	C30	1,500	1.93	0.5	0.4				72689	1.28		
	5	11.9	10/14/98	11/12/98	C32	1,500	0.47	0.5	0.4				70361	0.51		
4	3	6.7	11/17/98	12/16/98	C30	1,500	1.93	0.5	0.4				72689	1.28		
	13	7.3	11/17/98	12/17/98	C32	1,500	0.47	0.5	0.4				70361	0.51		

[1]In meters relative to mean lower low water.

Equipment locations, sampling configurations, and mounting parameters are summarized in Table 4-3. As noted in Table 4-2, one ADVOcean flooded during two separate deployments, shorting out the compass card. The compass card measures pitch, roll, and heading, which are used to convert the three measured beam velocities to velocities referenced to earth coordinates. Current speeds from the flooded ADVOcean looked reasonable, but the directions were obviously wrong. Data were corrected by using the compass values from the ADP mounted on the tripod above the ADVOcean, and incorporating the ADP compass values to calculate velocities referenced to earth coordinates. Quality checks for all deployments determined that the data were good.

Wave energy spectral analysis was performed to determine adequate high-frequency cutoff values. Energy distributions by frequency and direction were plotted for each data burst collected at each station. Typical spectra for the offshore station showed a single or double peak arriving at periods between 8 and 16 sec, indicating swell arriving from offshore (Figure 4-3).

Energy spectra for stations located east of the outer bar (inside the mouth of the bay) did not usually exhibit a distinct energy peak, with energy spread across frequency (periods between 4 and 10 sec). Figure 4-4 shows typical spectra at Station 2 (inside bay) throughout a tidal cycle. The plots show a decrease in energy density as ebb current speed increases and an increase in energy density as the flood current speed increases.

The differences in spectral shape between the offshore station and those inside the bay (specifically changes in wave energy distribution by frequency) are most likely caused by a combination of depth-limited wave breaking over the outer bar and the neglect, in the analysis, of changes in wavelength induced by currents. These changes in wave energy distribution by frequency made the task of choosing a high-frequency cutoff for the inner bay stations difficult. The following high-frequency cutoff recommendations by CHL were applied in the processing:

a. Station 1: 0.25 Hz.

b. Station 2: 0.21 Hz.

c. Station 3: 0.21 Hz.

d. Station 4: 0.25 Hz.

e. Station 5: 0.25 Hz.

Wave data for all stations were analyzed with the wave data analysis standard, spectral analysis program developed by ERDC and the Field Wave Gaging Work Unit at ERDC, Vicksburg, MS.[1] Routine processing of the wave data did not include changes in wavelength produced by wave-current interaction.

[1] Earl, M. D., McGehee, D. D., and Tubman, M. W. (1995). "Field Wave Gaging Program wave data analysis standard," Instruction Report CERC-95-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

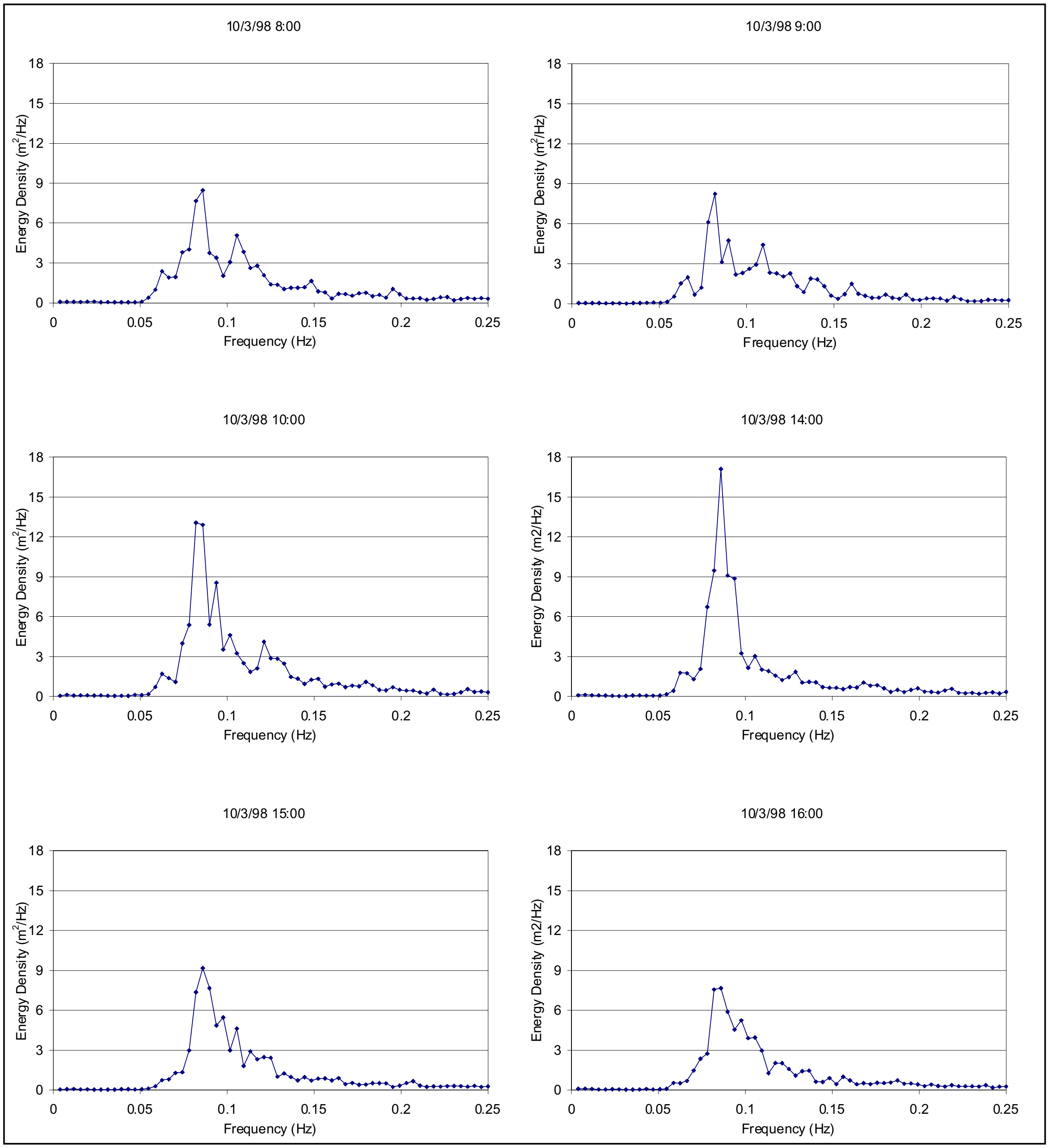

Figure 4-3. Energy density plots for Station 1

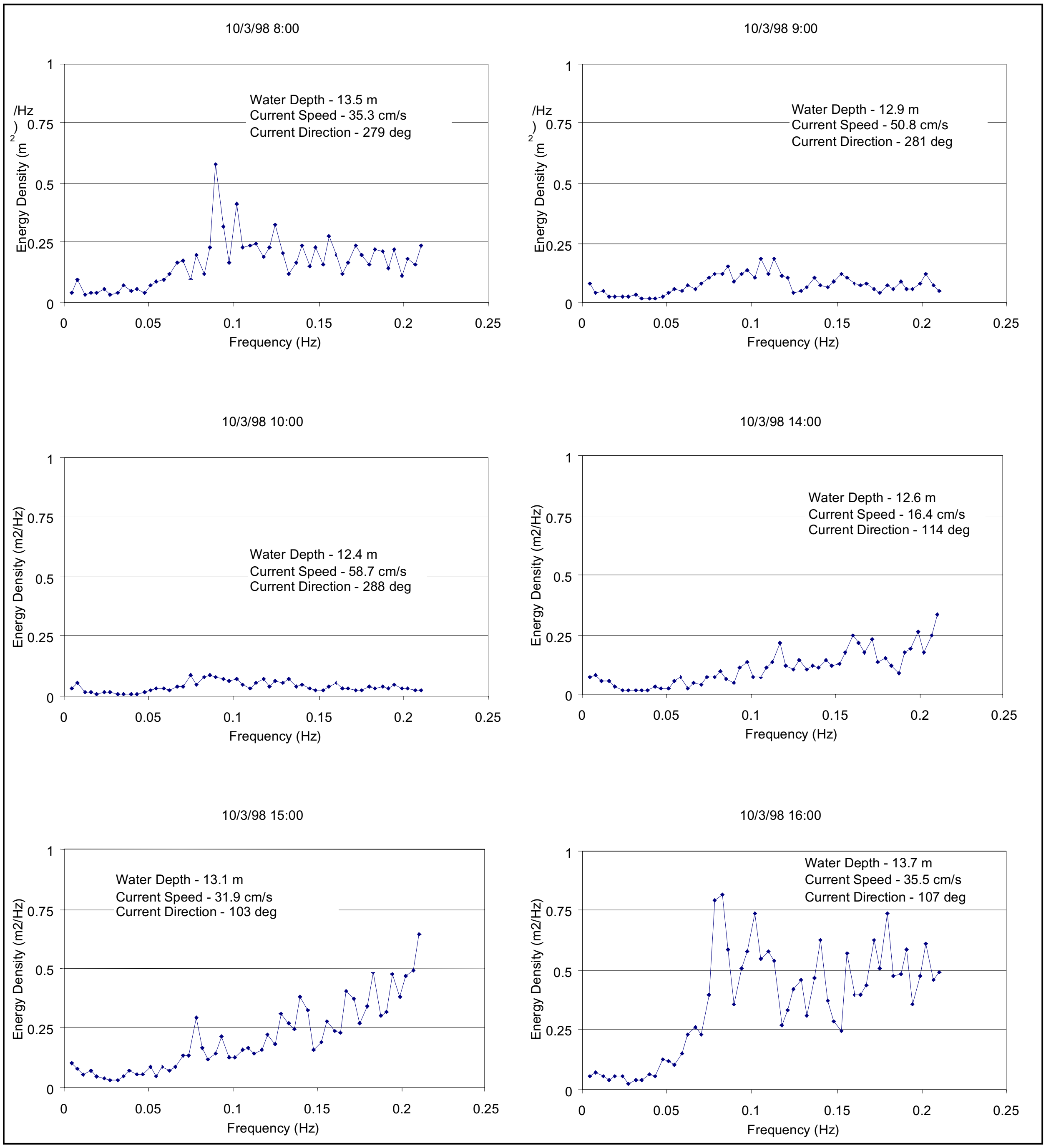

Figure 4-4. Energy density plots for Station 2

Wave height time series were generated and comparisons were made between Stations 1 through 5 and records from the buoy deployed at Grays Harbor, Washington. Figure 4-5 shows the wave height time-history for Deployment 2. Wave heights from Station 1 were similar to the wave heights collected from the Grays Harbor buoy. However, inside the bay, daily changes in wave height and peak period corresponded primarily to changes in water-surface elevation.

Figure 4-6 shows a comparison of Station 1 (west of the outer bar) and Station 2 (east of the bar) wave height and peak period during a typical tidal cycle. Figure 4-7 also shows water depth, current speed, and significant wave height on 3 October 1998.

ADVOcean averages of current speed and direction are shown in Table 4-4 for Deployment 3.

Table 4-4
ADV Data Averages 10-9-98 to 11-18-98

Station No.	Mean Current Speeds cm/sec		Mean Current Direction deg Relative to True North	
	Ebb	Flood	Ebb	Flood
1	16.5	10.9	287.7	76.6
2	41.1	27.3	312.0	111.0
3	44.6	40.5	263.5	99.1

Current Measurements

To define the current regime within the Willapa Bay study area, two measurement strategies were incorporated into the field plan. First, current meters were moored to obtain time series at specific locations (Figure 4-1). Second, to define regional variations in the structure of the current, and to better define the net movement of water in particular channels, the current was measured along transects. Transect data were recorded with a profiling Doppler current meter (RD Instruments (RDI), Acoustic Doppler Current Profiler (ADCP)) mounted over the side of a moving vessel. The instrument is capable of bottom tracking, which removes the velocity of the moving vessel from the recorded current data to retrieve the current velocity profile. Field service dates and the parameters measured at each station are summarized in Table 4-1.

Moored current measurements

Moored current measurements were made with ADPs. Current and wave instruments were deployed on the same bottom mounts as discussed in the wave measurement section (Figure 4-2).

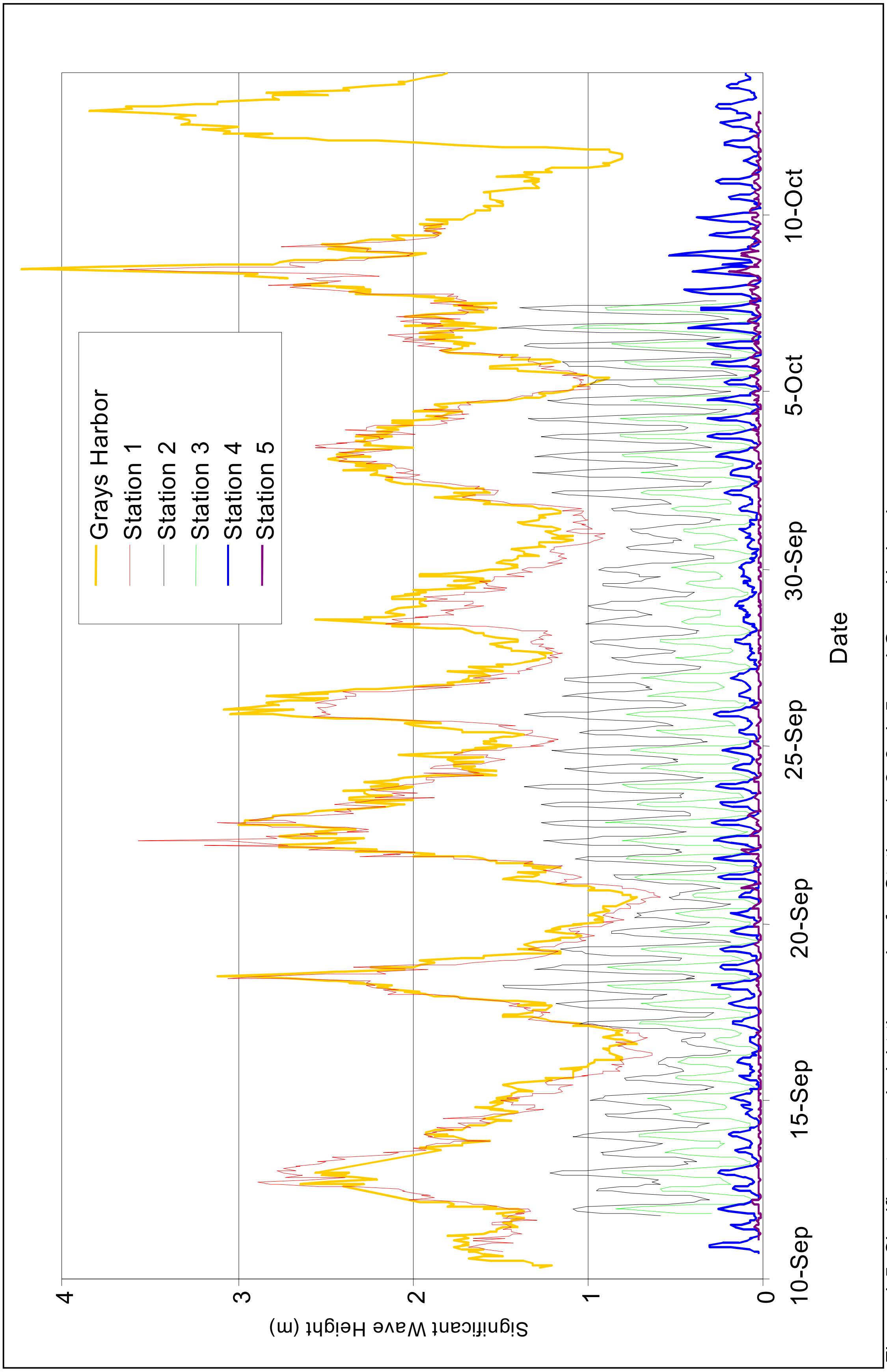

Figure 4-5. Significant wave height time series for Stations 1, 2, 3, 4, 5, and Grays Harbor buoy

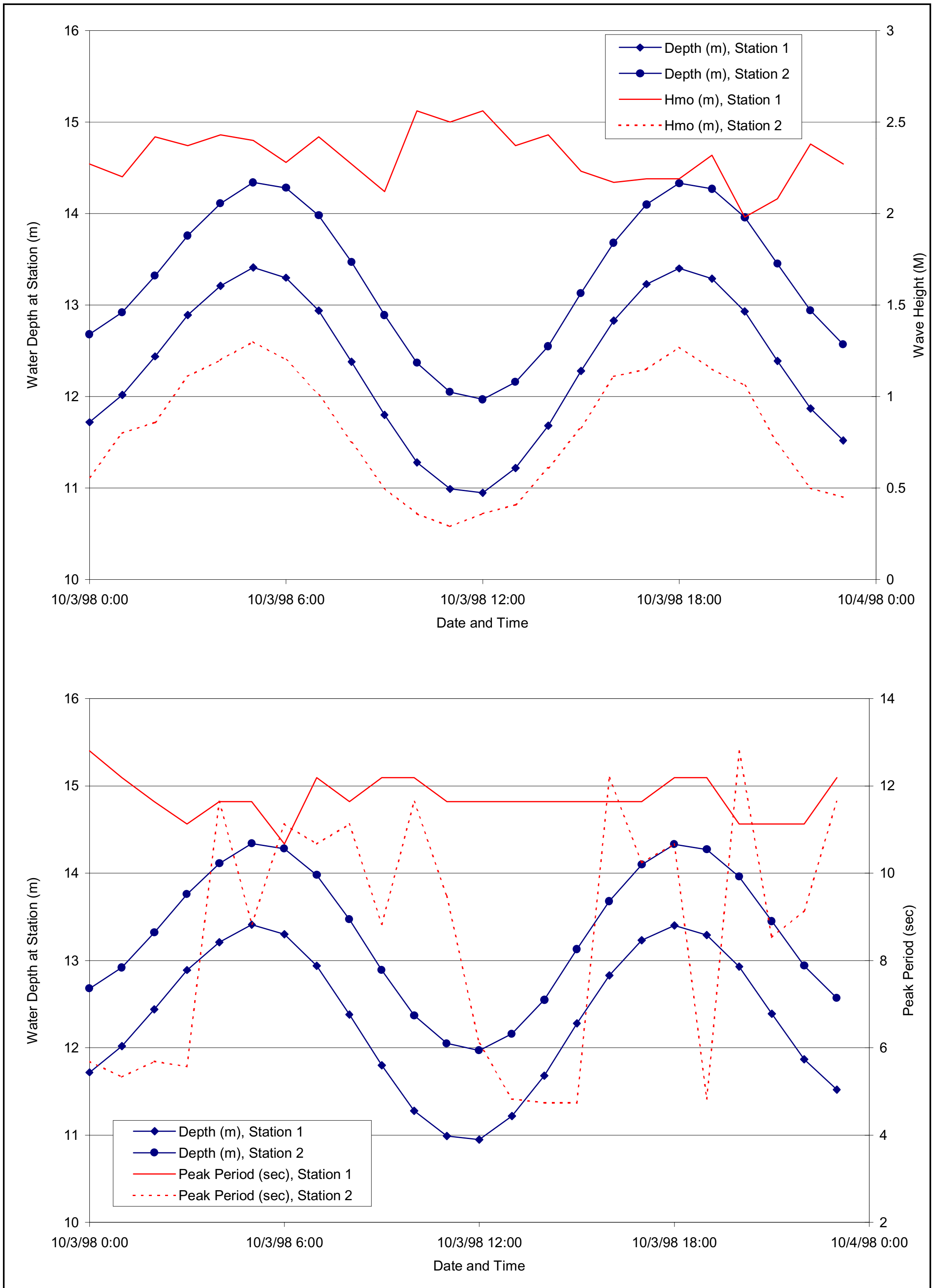

Figure 4-6. Comparison of Stations 1 and 2 wave heights and peak periods

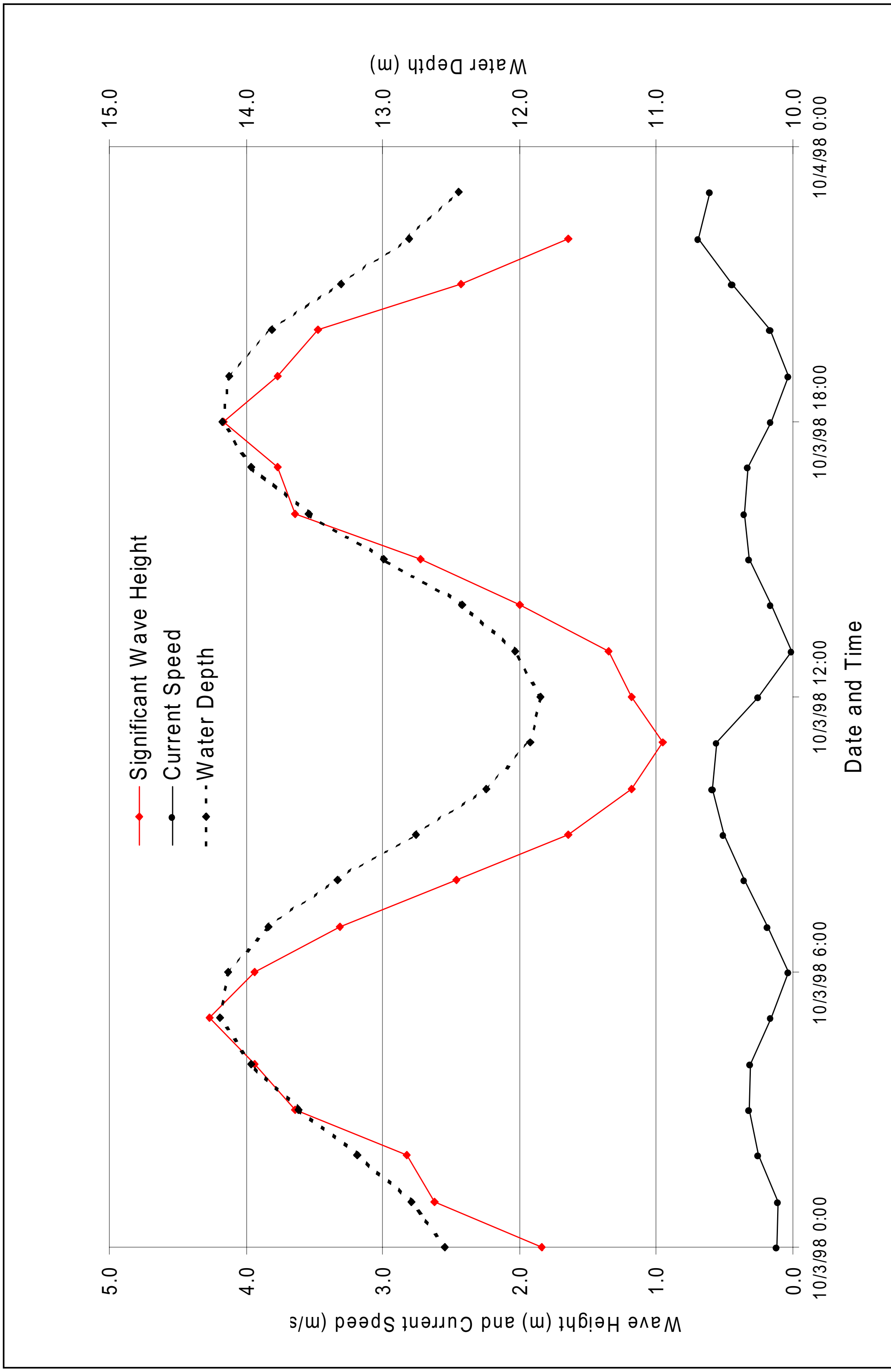

Figure 4-7. Station 2 wave height, water depth, and current speed for 3 October 1998